2018

TRENCHLESS SANS TRANCHÉE Journal

THE OFFICIAL PUBLICATION OF THE NORTH AMERICAN SOCIETY FOR TRENCHLESS TECHNOLOGY
Great Lakes, St. Lawrence & Atlantic Chapter | Chapitre des Grands-Lacs, du Saint-Laurent et de l'Atlantique

- Urban Tunnelling in the City of Ottawa
- Pipe Bursting Challenges in the City of St. Catharines
- Historic Drinking Water Tunnel Inspection Using Remote Technologies

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ON THE COVER: Autumn views of Ottawa and the Parliament buildings. © Leo Bruce Hempell Dreamstime.com

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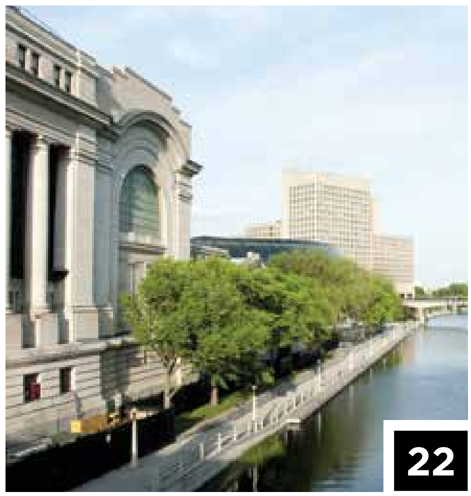

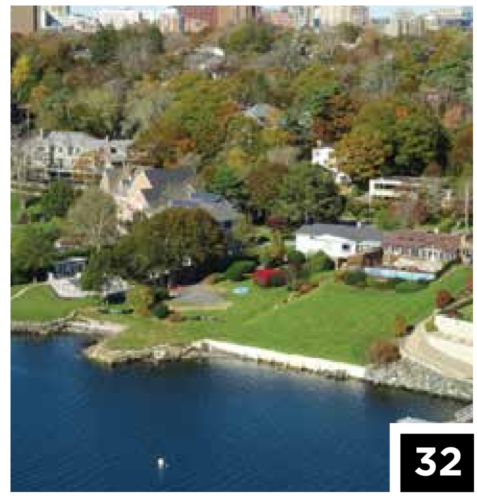

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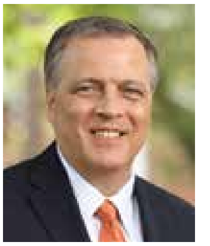


Grassroots Involvement

Hello GLSLA members! As the year marches along we are looking forward to the continued growth of the trenchless industry and our Society. It was exciting to host NASTT's 2018 No-Dig Show in Palm Springs, California. The conference was very successful on all accounts. The exhibit hall featured close to 190 exhibitors and we welcomed more than 2,000 attendees from all over the world who came to experience the world class technical sessions and networking events that our Show is known for. NASTT's 17th Annual Educational Fund Auction was, once again, the trenchless social event of the year and we raised nearly $100,000 for our educational programs! Thank you all for your generous support.

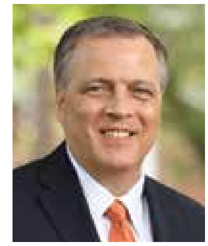
NASTT exists because of the dedication and support of our volunteers and our 11 regional chapters. Plans are now underway for the 2019 conference in Chicago, Illinois. Our No-Dig Show Program Committee members are volunteering their time and industry knowledge to peer-review the abstracts. These committee members ensure that the technical presentations are up to the standards we are known for. Thank you to the GLSLA Chapter members who have volunteered for this important task this year: Frank Badinski, David Crowder, Brenda Kingsmill, Michael Kleespies, Derek Potvin, Ashely Rammeloo, and Michael Willmets.

We are offering two complimentary webinars this fall, where you can get free, high-quality trenchless training without even leaving your desk! Join us in October and November for *Introduction to Trenchless Rehabilitation* and *New Installations.* These webinars will offer overviews of trenchless technology and are great for those new to our industry or those wanting to get a taste of the various types of trenchless technology they may not be familiar with. Attendees receive education from the convenience of their home or office, yet are able to actively participate using a Q&A platform. NASTT's webinars are always accurate and objective, contain no commercial content, and are free to both members of NASTT and non-members. Visit our webinar page for more information: *nastt.org/training/webinars.*

"We are offering two complimentary webinars this fall, where you can get free, high-quality trenchless training without even leaving your desk!"

The North American Society for Trenchless Technology is a society for trenchless professionals. Our goal is to provide innovative and beneficial initiatives to our members. To do that, we need the involvement and feedback from our professional peers. If you are interested in more information, please visit our website at *nastt.org/volunteer.* There, you can view our committees and learn more about these great ways to stay active with the trenchless community and to have your voice heard.

Our continued growth relies on the grassroots involvement of our regional chapter advocates. Thank you again for your support and dedication to NASTT and the trenchless technology industry.



Des régions dynamiques

« Au calendrier de cette année : deux webinaires gratuits. Deux occasions de se former sans frais et sans quitter son bureau! »

Bonjour, chers collègues de la GLSLA! L'année s'achève, mais notre industrie et notre Société poursuivront leur essor, espérons-le! Quel plaisir et quel succès que le No-Dig Show de cette année, à Palm Springs (Californie). Près de 190 exposants animaient la salle qui leur était réservée, et plus de 2000 participants de partout au monde ont assisté aux présentations techniques de premier ordre et ont pris part aux activités de réseautage qui font la réputation du salon. Une fois de plus, la vente aux enchères pour le financement du fonds d'éducation de la North American Society for Trenchless Technology (NASTT) a été l'activité sociale de l'année. Cette 17e édition a permis de recueillir près de 100 000 $ pour nos programmes de formation. Merci à tous de votre générosité!

La NASTT existe grâce au dévouement des bénévoles et de nos onze sections régionales. Déjà, la planification du congrès de 2019, qui aura lieu à Chicago (Illinois), va bon train. Les membres du comité des programmes donnent leur temps et mettent leur connaissance de l'industrie à profit pour réviser les résumés des présentations proposées par leurs collègues et s'assurer qu'elles respectent les normes de qualité qui nous caractérisent. Merci aux membres de la section Grands Lacs, Saint-Laurent et Atlantique (GLSLA), qui se sont une fois de plus portés volontaires pour cette tâche importante, soit : Frank Badinski, David Crowder, Brenda Kingsmill, Michael Kleespies, Derek Potvin, Ashely Rammeloo et Michael Willmets.

Au calendrier de cette année : deux webinaires gratuits. Deux occasions de se former sans frais et sans quitter son bureau! Soyez des nôtres en octobre et en novembre prochain pour *Introduction to Trenchless Rehabilitation* (introduction à la remise en état sans tranchées) et *New Installations* (nouvelles installations). Il s'agit d'un survol de la technologie sans tranchées, précieux pour ceux qui abordent le domaine et ceux qui veulent avoir un aperçu de diverses technologies qui leur sont moins familières. De la maison ou du bureau, vous pourrez participer activement grâce à la plateforme Q&A. Les webinaires de la NASTT, gratuits pour les membres et les non-membres, regorgent d'informations exactes et objectives, libres de tout contenu commercial. Consultez la page *nastt.org/training/webinars* pour en savoir davantage.

La NASTT regroupe des professionnels de l'industrie, à qui elle se fait fort de proposer des initiatives innovantes et pertinentes. Or, nous ne saurions y parvenir sans votre participation et votre rétroaction. Pour en savoir davantage sur le travail bénévole, rendez-vous sur notre site Web, à la page *nastt.org/volunteer*. Vous y trouverez la liste de nos comités et d'excellents moyens de participer activement à la communauté des praticiens et d'exprimer votre opinion.

L'essor de notre industrie repose sur l'implication des membres de nos sections régionales. Merci encore de votre appui et de votre dévouement à la NASTT ainsi qu'à l'industrie de la technologie sans tranchées.

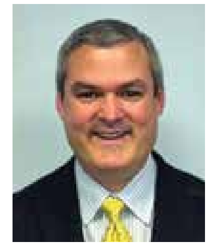
Call for Submissions

If you would like to submit your project paper or other content and photos for an upcoming issue of this GLSLA Chapter magazine, please contact David Crowder, the Trenchless Journal Coordinator, at *dcrowder@rvanderson.com*.

Editorial submissions are welcome, and are due for the next publication by July 26, 2019 .

Kevin Bainbridge, *GLSLA Chapter Chair*

Trenchless Industry Riding High



The Great Lakes, St Lawrence and Atlantic (GLSLA) Chapter of NASTT is pleased to present our 2018 issue of the *Trenchless Journal*. This magazine is filled with lots of product and project information, NASTT updates, and some great articles including a significant tunnelling project in the City of Ottawa.

Trenchless technologies are riding high in the industry across Canada and the GLSLA region, with continued growth of projects in both new installation and rehabilitation. Trenchless technologies are now mainstream and not just an option when traditional methods are not feasible. The industry has reached a critical mass of work and this creates exciting opportunities for investments in the advancement of the industry. There has never been a better time to be working in the industry and GLSLA looks forward to continuing our mission of education and awareness of trenchless technologies.

> "There has never been a better time to be working in the industry"

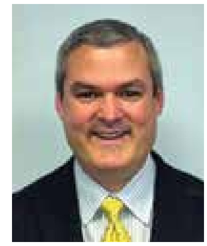
The GLSLA Board of Directors and member volunteers are continuing to work to provide value to our members through this publication along with training, our website and support for several NASTT programs, including the Municipal Scholarship and silent auction. We encourage members to get involved with these programs as they provide significant value to members and the industry as a whole.

GLSLA also continues to support NASTT in educational initiatives, including most recently NASTT's complimentary webinars run this fall. These webinars represent a great opportunity for members to gain valuable knowledge from industry leading practitioners with years of experience in the trenchless industry.

Trenchless Technology magazine recently announced its project of the year awards and GLSLA would like to congratulate Halifax Water, Robinson Consultants, CBCL, Liquiforce Services, Insituform Technologies, Unijet, Empipe, and Atlas Dewatering for being recognized as the 2018 Project of the Year runner up (see article on page 32).

We look forward to the upcoming events including the 2019 No-Dig show in Chicago.

For more information on GLSLA, our events, and our training sessions, or to contact us if you wish to publish an article in our magazine, please visit our website at *www.glsla.ca.*



De succès en succès

La section Grands Lacs, Saint-Laurent et Atlantique (GLSLA) de la North American Society for Trenchless Technology (NASTT) présente avec fierté le numéro du Journal Sans Tranchée de 2018. Vous y trouverez une foule de renseignements sur des produits et des chantiers et sur les activités de la NASTT, ainsi que d'excellents articles sur les travaux d'envergure qui entourent le percement d'un tunnel dans la ville d'Ottawa.

Les technologies sans tranchée vont de succès en succès au Canada en général, et dans la région GLSLA, où foisonnent les chantiers d'installation et de réfection. Elles s'imposent maintenant en toutes circonstances et non plus seulement comme solution de rechange quand les méthodes habituelles sont inapplicables. Le nombre et l'ampleur des chantiers invitent plus que jamais à investir dans la promotion de l'industrie. La section GLSLA n'en est que plus déterminée à poursuivre sa mission de formation et d'information.

Les administrateurs et les bénévoles de la section travaillent sans relâche à bonifier l'offre aux membres, par le biais de cette publication, mais aussi par les formations offertes, le site Web et le soutien financier à nombre des programmes de la NASTT, y compris les bourses aux employés municipaux et les bourses d'études ainsi que les ventes aux enchères par écrit. Nous invitons les membres à participer à ces programmes si utiles aux membres et à l'industrie dans son ensemble.

La section GLSLA soutient en outre les initiatives de formation de la NASTT et, parmi elles, les webinaires gratuits de cet automne, qui donnent aux membres une occasion inégalée d'approfondir leurs connaissances grâce à d'excellents praticiens qui n'hésitent pas à partager leur substantielle expérience.

> « Le nombre et l'ampleur des chantiers invitent plus que jamais à investir dans la promotion de l'industrie. »

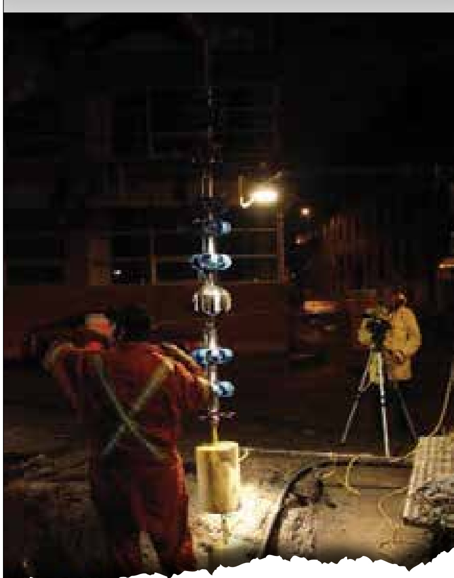
Le magazine Trenchless Technology vient de publier les noms des lauréats de ses prix annuels. La section GLSLA tient à féliciter Halifax Water, Robinson Consultants, CBCL, Liquiforce Services, Insituform Technologies, Unijet, Empipe, ainsi que la société Atlas Dewatering, qui a atteint la seconde marche du podium (voyez l'article à la page 32).

Quel plaisir en perspective que les activités à l'horizon de 2019, y compris le No-Dig Show, à Chicago!

Pour en savoir davantage sur la section GLSLA, nos activités et nos formations, ou sur la marche à suivre pour publier un article dans notre magazine, consultez notre site Web, à l'adresse *www.glsla.ca*.

GOOD DECISIONS START

WITH GOOD INFORMATION



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Historic Drinking Water Tunnel Inspection Using Remote Technologies

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ASI Marine L.P. (ASI), a company specializing in underwater inspection work, was subcontracted to provide underwater inspection services using remote (un-manned) technologies at a tunnel owned by a municipality in northern CA.

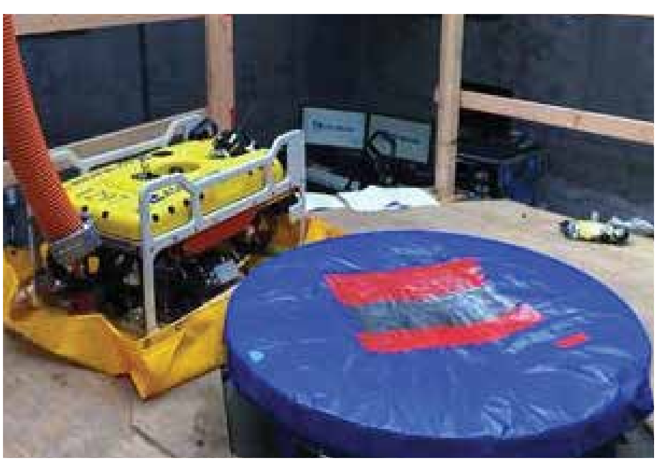
Brought into service in October of 2014, the 5-mile-long by 9-foot-diameter tunnel delivers drinking water from several reservoirs to approximately two million customers in the area. As the first tunnel built under the bay, it replaces aging pipeline infrastructure built in the 1920s and 1930s and traverses the bay on wooden trestles, providing seismic and delivery reliability in the event of a major earthquake.

The primary objective of ASI's inspection was to utilize remote inspection technologies to collect data for assessing the general condition of the tunnel for purposes of warranty inspection. Anomalies, accumulation, and/or tunnel damage were to be identified, documented, and provided in the associated report deliverables.

Understanding that the tunnel is a potable water supply, ASI was required by the municipality to follow ASI's procedure for invasive mussel mitigation of remote inspection technologies prior to mobilization of equipment and personnel to the job side in order to mitigate the transfer of invasive mussels into the drinking water system. This procedure consists of submersing the remotely operated vehicle (ROV) to be used for the inspection, along with its onboard sensors, in a hot water bath for a set period of time to ensure 100% mortality of any mussel veligers.

ASI conducted the ROV inspection from two points of access during a planned tunnel outage with client and municipal representatives present to observe the inspection and direct the ROV pilot to areas of interest. ASI utilized its Falcon ROV retrofitted with various data collection technologies, including two-dimensional imaging sonar, profiling sonar, and high-definition video cameras.

Imaging sonar capabilities allowed for detection of tunnel lining damage and/or obstructions (if any) ahead of the ROV. Profiling sonar was used to measure and report any general



tunnel distortion and sediment and debris accumulation along the invert of the tunnel. Video capabilities provided continuous viewing for the duration of the inspection, which was completed within a one-week period.

Upon the successful inspection completed by ASI, the municipality flushed the tunnel and conducted bacteriological tests. The tunnel was returned to service weeks after the inspection. 🍁

Courtesy of:
North American Society for Trenchless Technology (NASTT)
NASTT's 2018 No-Dig Show
Palm Springs, California, March 25–29, 2018

Pipe Bursting Challenges in the City of St. Catharines

Dave Holcomb, TT Technologies, Inc., Aurora, Illinois
Steve Kottelenberg, AVERTEX Utility Solutions, Inc., Amaranth, Ontario

ABSTRACT

Every pipe bursting project should be evaluated based on the complete data set of information available. The data should be thoroughly vetted by the design engineer, owner, and contractor in order to get a clear picture of the project complexity. This evaluation should be done during the life cycle of the project from design through construction. Every project has its own unique set of challenges, which are made easier to face when they are planned challenges.

The static pipe bursting project located in the City of St. Catharines in Ontario was one such project with many planned challenges. Avertex Utility Solutions Inc. out of Ontario has been in the underground business since 2003 so they have seen their share of challenges. This particular project, although short in pipe length, was long on challenges. The project consisted of replacing a 230-foot (70 m) section of 18-inch (450 mm) PVC gravity feed sanitary sewer pipe, 32 feet (10 m) deep, located between two houses, collapsed down to 4 inches (101 mm) with very high flow with 18-inch (450 mm) HDPE. The owner, design engineer, and contractor had to come up with a plan for all of these challenges.

This article will focus on how the challenges of pipe bursting a high flow line with extreme pipe collapse, pipe depth, and sensitive confined residential workspace were planned for and overcome and how HDD, pipe bursting, and bypass pumping were utilized to complete the project.

INTRODUCTION: STATIC PIPE BURSTING METHOD OVERVIEW

Hydraulically operated static bursting systems with bladed rollers has provided an alternative to pneumatic pipe bursting that has become valuable in a wide range of pipe replacement situations. These static bursting systems are able to burst/split and replace ductile iron and steel pipes.

In the static process, exit and launch pits are used in the same way they are for pneumatic bursting. First, the hydraulic bursting unit is positioned in the exit pit. Then the bursting rods are pushed through the host pipe and into the launch pit. Patented Quicklock bursting rods are linked not screwed together like traditional drill stems or other static systems. This system speeds the installation process as well as the breakdown procedure. The rods can be quickly removed one at a time at the exit pit as bursting is in operation. A flexible guide rod helps the bursting rods navigate through host pipe as shown in Figure 1.

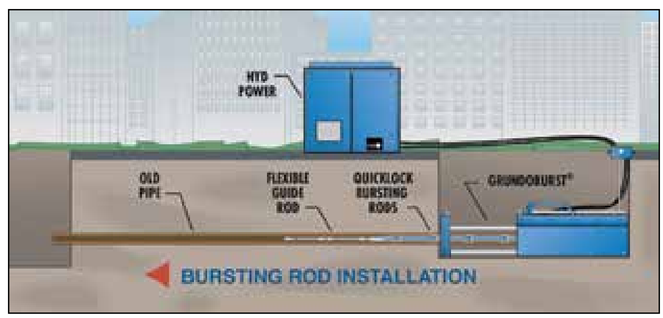


Figure 1. Typical static pipe bursting set-up.

The flexible guide rod allows the bursting rods to navigate the typical imperfections found on the inside of the host pipe such as sags, humps, dropped joints, debris, and other obstacles. At the launch pit, the flexible guide rod is removed. The bladed rollers, bursting head, expander and new pipe are then attached as shown in Figures 2 and 3. The specially designed bladed rollers

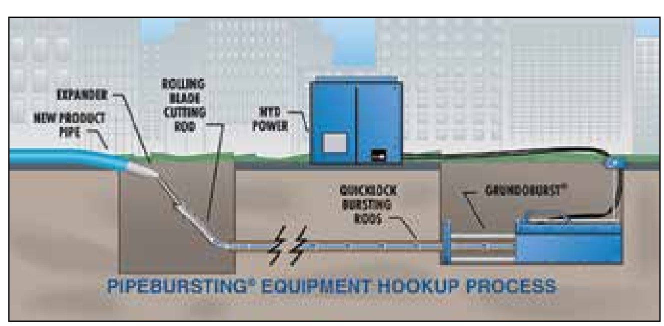
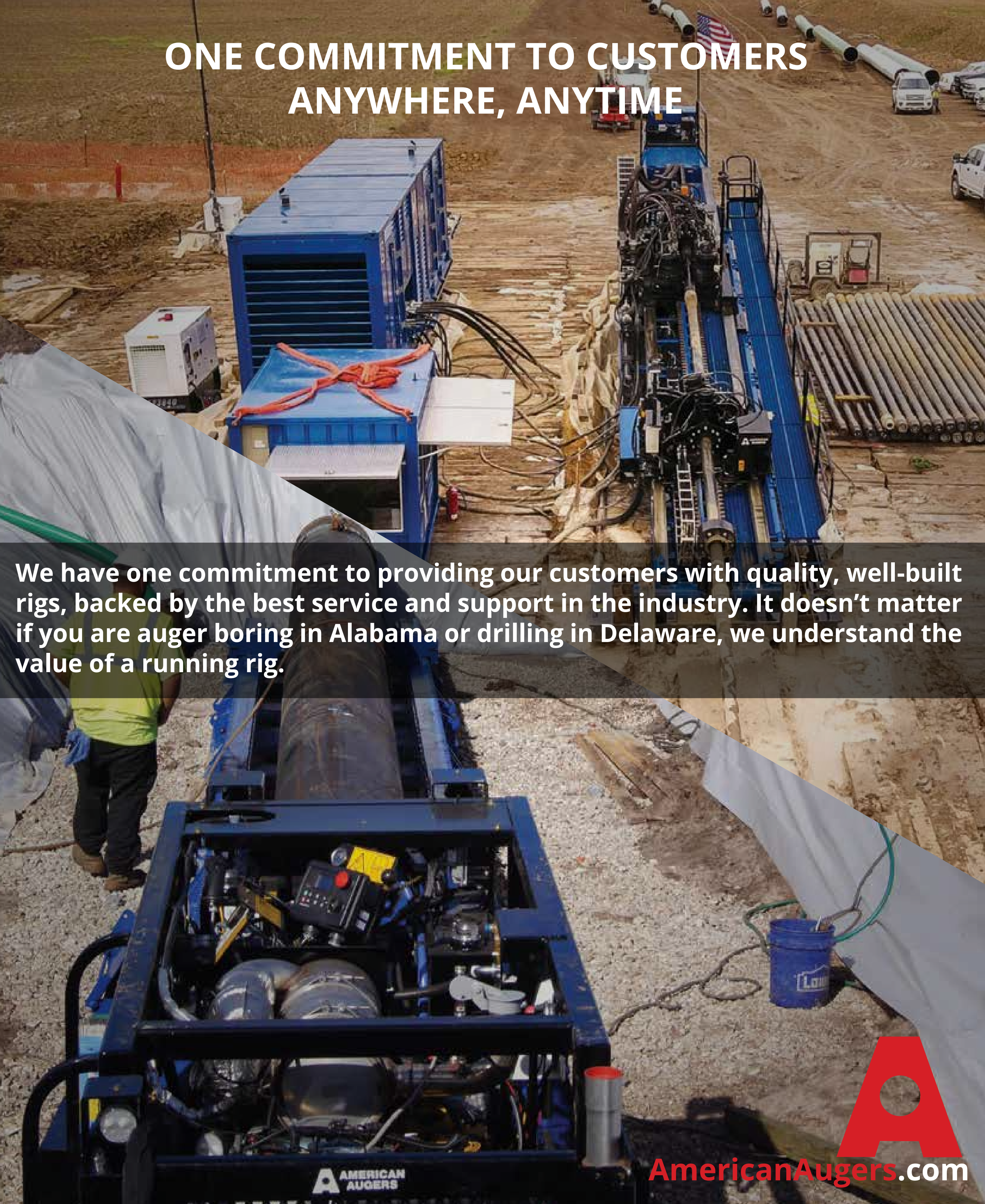


Figure 2. Bursting configuration attached and pullback begins.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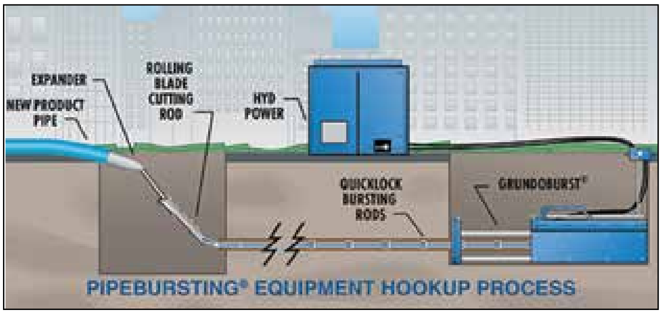


Figure 3. Host pipe is split and displaced, while new pipe pulled into place.

actually split the host pipe instead of ripping or tearing it. The entire configuration is pulled back through the host pipe by the hydraulic bursting unit. The bladed rollers split the existing pipe, while the bursting head and expander displace the fragmented host pipe into the surrounding soil. The new pipe is pulled into place simultaneously.

Other pipe materials may be installed in certain situations. Potential pipe materials include: restrained joint ductile iron pipe, restrained joint PVC pipe, among others. For the St. Catharines project, the static pipe bursting method was chosen in conjunction with directional drilling.

PROJECT BACKGROUND

At the time of tender by the City of St. Catharines this project was designed to replace a 230-foot (70 m) section of 18-inch (450 mm) PVC sanitary, which had almost fully collapsed, through an easement running between houses from a local street to a Hydro Utility transmission easement by installing a steel casing by directional drilling in one of two ways:

a) In the same location as the existing sewer and reusing both manholes on either end.
b) In a new location beside the existing sewer, but reusing one of the existing manholes and installing an intermediate manhole. These options are noted on the below tender drawings, Figures 4 and 5.

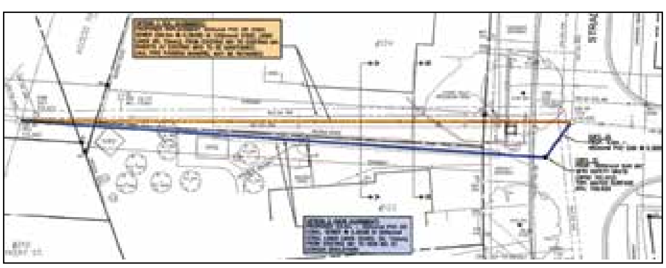


Figure 4. Tender drawing for sewer line replacement.

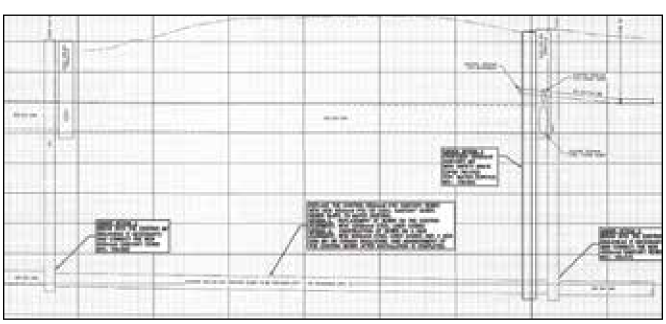


Figure 5. Tender drawing for sewer line replacement.

As it is not feasible to directional drill in the same location of an existing pipe and pull back a steel casing while removing the existing PVC with an HDD reamer, Avertex notified the city representative that the tender could not be bid as designed by the City and that a price submitted would be for a design-build to find a solution to the situation.

The city was receptive to this idea and so Avertex proceeded to bid the project based on completing a pipe burst of the existing 18-inch (450 mm) PVC sewer and pulling back an 18-inch (450 mm) HDPE in the same alignment without the installation of a steel casing, and reusing the existing manholes on either end of the alignment. The Avertex proposal was a significantly better option financially for the City than other bids. After award of the project, Avertex submitted the following plan to the City as a proposal for execution of the work, Figure 6.

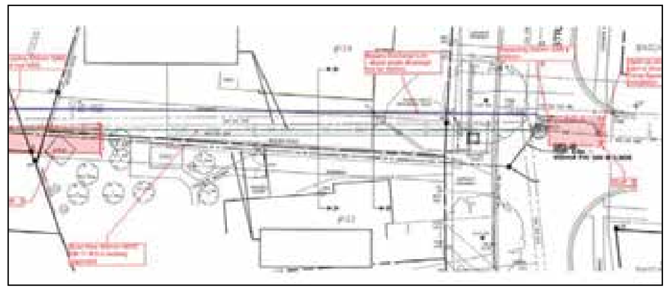


Figure 6. Updated plan including static pipe bursting and directional drilling.

PROJECT CHALLENGES

The biggest challenge on the project was installation of the shoring system as there were fences, sheds, existing utilities, and other items that needed to be relocated or diverted. In addition, the extreme depth of the pipe, approximately 30 feet deep (9.5 m), added an additional level of complexity to the project, Figure 7. The impact of the ground pressure from the swelling clay native material being placed on the existing, collapsed pipe was also concerning, as it could not be said for sure ahead of time if a burst would be successful.


Figure 7. Extreme pipe depth created a challenging work environment.

Avertex used the static pipe bursting system to launch from the upstream shaft and pull pipe back, while expanding the existing collapsed pipe, through the existing alignment from a downstream shaft. A directional drill was used to bore from the surface to the downstream shaft location to allow for pipe installation, Figures 8 to 10.

Figure 8. A directional drill was used to create a window down to the existing pipe on the launch side of the project. This allowed Avertex to limited street disruption and restoration.

Figure 9. A static pipe bursting unit was used to burst and replace the collapsed PVC pipe.

"The **biggest challenge** on the project was **installation** of the shoring system as there were **fences, sheds, existing utilities,** and other items that needed to be **relocated or diverted**."

Figure 10. The static pipe bursting unit delivers 214 tons (427,137 bar) of pullback.

The static bursting equipment performed well. The machine reached higher end pullback levels after initially reaching the collapsed section of pipe. Once through the collapsed section, the pullback force was lower for the remainder of the pullback, Figures 11, 12, and 13.

Figure 11. The low profile of the Quicklock bursting rods allowed Avertex to rod the existing PVC line, even though it had collapsed significantly.

"Second, this project also serves as a reminder that **educating** people on the available uses of trenchless technology needs to **be ongoing**."

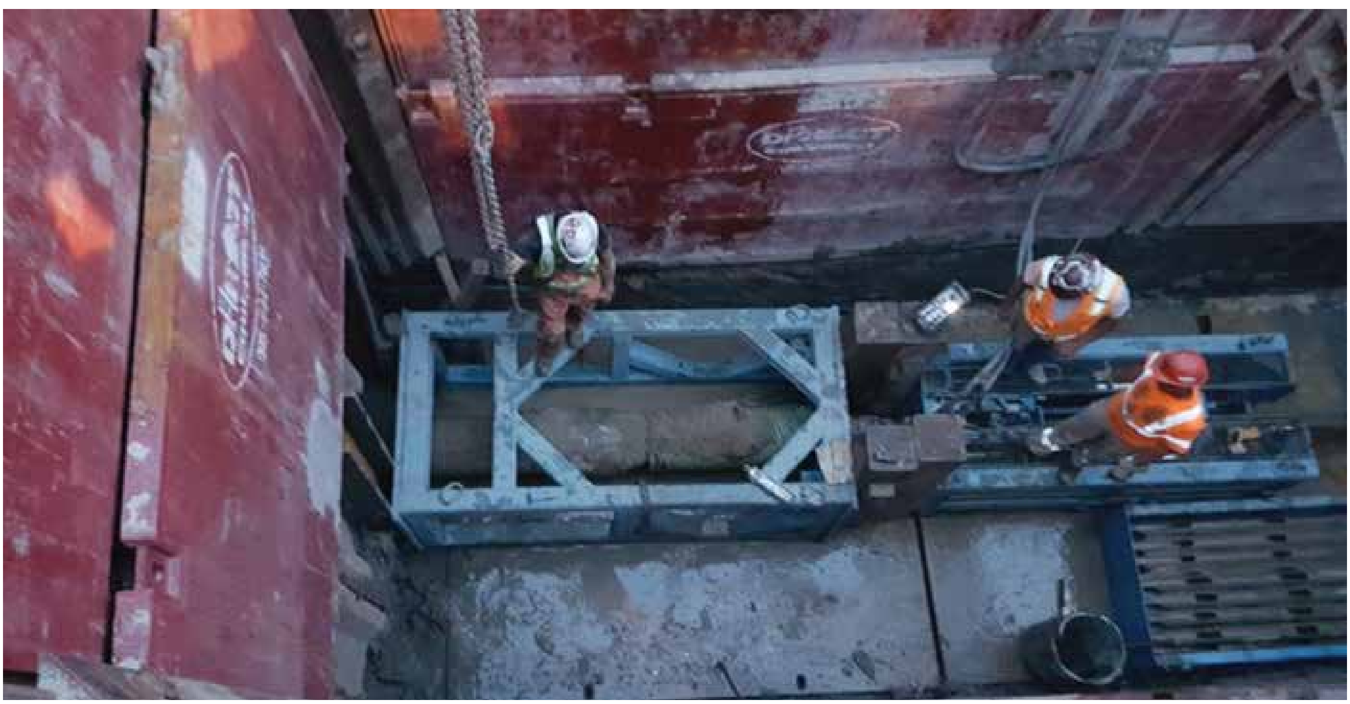


Figure 12. An extension frame on the pipe bursting unit provides the space between the wall of the shaft and the machine to facilitate the entry of the new pipe.

"The extreme depth of the pipe, **approximately 30 feet deep (9.5 m)**, added an additional **level of complexity** to the project."

Figure 13. The new 230-foot (70 m), 18-inch (450 mm) diameter HDPE pipe successfully installed.

CONCLUSION

The combination of trenchless methods was a significant aspect of this project and its overall success. The availability and capability of the static pipe bursting technology allowed Avertex to approach this project from a different standpoint than the City had initially designed. Several important lessons can be learned from this project. First, trenchless methods are dynamic and combining them can result in greater project flexibility and effectiveness.

Second, this project also serves as a reminder that educating people on the available uses of trenchless technology needs to be ongoing. Even though many of these trenchless methods have been around for several decades and many engineers and municipal entities may understand the benefits of using these technologies, they may not necessarily understand the capabilities and limitations of them in a practical on the job site settings. This highlights the importance and continuing need of quality trenchless education programs and opportunities.

Finally, cooperation is key. The proposal, equipment, and cooperation from every party involved allowed for a successful project and left everyone pleased with the end product.

Trenchless Point Repair in the GTA: A Cured-in-Place Case Study

Cities across Canada are constantly faced with stretching budget dollars to improve and repair the underground infrastructure. With an eye on the bottom line, new repair methods and technology are needed to increase work capacity and productivity each day.

As the demand for an environmentally-friendly service for infrastructure rehabilitation has increased rapidly throughout Canada, the disruption of a traditional dig and replace method of repair is no longer feasible. Municipalities and contractors are turning their focus to Cured-In-Place-Pipe (CIPP) joint and spot repairs. This technology gives municipalities, businesses, and homeowners a productive flowing system with an added assurance of a 50-year service life.

After originating in Europe in the 1970s, CIPP underground repairs have evolved with new processes and procedures to improve on the original idea. With upcoming technology, trenchless repairs area inexpensive and quick – allowing organizations to avoid costly dig and replace excavations. Minimal equipment is needed for the repair, and repair crews are kept safe and small with increased productivity.

Recently, The Regional Municipality of Peel in Ontario needed to repair a 200 mm diameter sewer main that had a broken section. The water infiltration was causing an impact on the flow and the subsequent ground infiltration was causing a sag in the street. The main was located on Highway 10 (Hurontario Street) south of Highway 401, which would have typically required a standard dig and replace job. This would have resulted in shutting down the south-bound lanes on a major artery in the City of Mississauga.

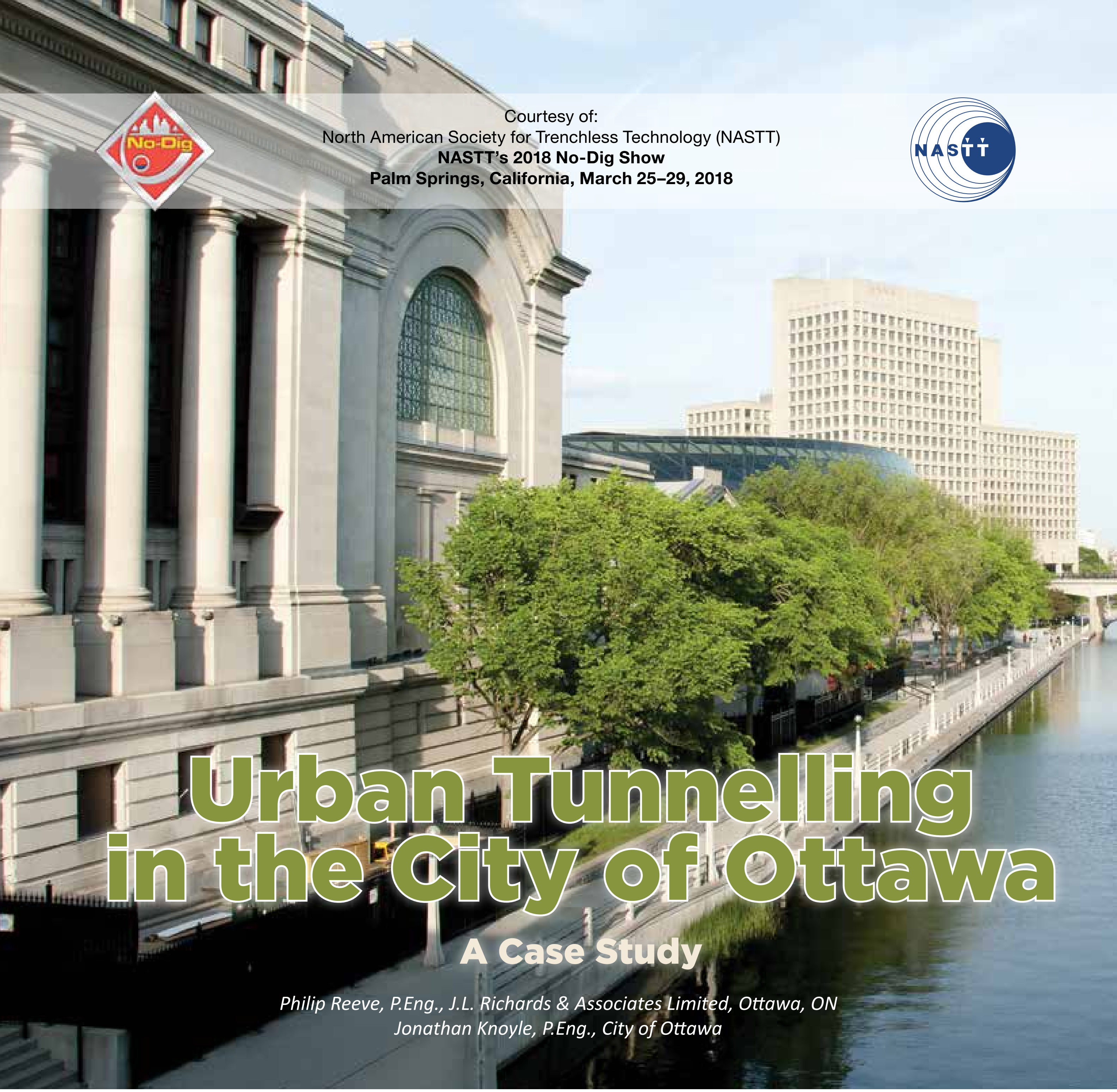
Looking for a solution that would avoid traffic disruption and costs, the Region of Peel turned to trenchless spot repair techniques. Using a CIPP process to eliminate the need for digging, a spot repair is completed with minimal change to the original inner diameter of the host pipe. This is like putting a stent in an artery, with the added materials reinforcing the existing wall and keeping the passage open. Through this process, not only does a spot repair stop the infiltration, but it also improves the flow within the storm and sanitary sewer system. When compared to digging or lining an entire pipe, trenchless spot repair only repairs areas that require rehabilitation, saving time, investment, and labor.

To prepare for the trenchless spot repair installation, a section of the road was cornered off and a vacuum truck was brought to the jobsite in case of high flow. From start to finish, a trained and certified city crew of five people completed the repair in four hours and saved the municipality thousands of dollars over a repair method that would have involved a dig. The sewer main was structurally repaired with only 3 mm change to the original diameter. Not only was the public and environment undisturbed during the installation, but the rehabilitation added decades of additional service life to the pipeline.

The product used in the repair was Source One Environmental's PipePatch, which has been used by Peel Region since June 2015. Since then, more than 30 CIPP repairs in both sanitary and storm, laterals and mains have been successfully completed, including repairs made by custom-sized repair patch kits. Within the kits is an ambient cure resin which will cure even in the presence of water. An additional benefit to the trenchless point repair CIPP method is that all the necessary patches and resins are supplied in pre-measured sizes and quantities, reducing waste, removing guesswork, and eliminating the need to maintain large inventories of kits. Kits are available in sizes ranging from 50 mm to 1,800 mm in diameter, in either 610 mm or 1,220 mm lengths.

Through discussion with municipalities and contractors, cities across Canada are taking note of trenchless point repair benefits to save money and time. By repairing and improving Canada's existing infrastructure using different CIPP methods, the country can strategize and budget for future asset management.

Courtesy of:
North American Society for Trenchless Technology (NASTT)
NASTT's 2018 No-Dig Show
Palm Springs, California, March 25–29, 2018



Urban Tunnelling in the City of Ottawa

A Case Study

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ABSTRACT

Built in stages between the early 1940s and 1960s, the culvert structure conveying Nepean Creek under Prince of Wales Drive to the Rideau Canal was a combination structural plate corrugated steel pipe and reinforced concrete frame culvert. Renewal was required due to significant deterioration of the structure and erosion at the outlet that caused collapse of the northeast wingwall, and a slope failure in the east embankment.

Sliplining alone of this 10 m deep, 65 m long culvert could not provide the required hydraulic capacity because of the physical restrictions of the culvert's composite section. After an exhaustive review of renewal alternatives, a solution that included sliplining the existing structure and tunnelling a new 2,100 mm diameter culvert parallel to it was identified as one that met the hydraulic requirements and minimized disturbance to sensitive environmental features and to the travelling public. It also provided considerable constructability advantages, as the work could be sequenced to allow flow to be maintained by gravity through the existing culvert during tunneling, and then through the completed tunnel during sliplining.

Prince of Wales Drive is an urban arterial roadway with status as a "Scenic Entry Route" into Canada's capital city. The watercourse being conveyed under the roadway through the culvert drains directly into the Rideau Canal, a World Heritage Site. The soil conditions were mostly highly variable embankment fills as a result of general

urbanization over the years. The unique setting, performance requirements, and soil conditions presented significant challenges during design and construction.

This paper reviews those critical elements as a case study of the challenges and inherent risks of tunnelling in a sensitive urban environment, and explores the pragmatic measures implemented to mitigate those risks and to manage unanticipated conditions during construction.

Introduction

The City of Ottawa (City) recognized the need to renew the Prince of Wales Drive bridge culvert structure, located under Prince of Wales Drive just south of Fisher Avenue, in the late 1990s. A design was prepared (by others) for a traditional open cut replacement of the culvert. For reasons that remain unclear, construction did not proceed. In 2012, the City commissioned a thorough culvert assessment (prepared by others) that identified significant structural concerns and recommended a number of alternate solutions for immediate replacement.

In 2013, J.L. Richards & Associates Limited (JLR) was retained by the City via a competitive consultant selection process to review the suggested alternatives, develop a recommended construction approach, prepare preliminary and detailed design, secure necessary approvals, prepare tender documents, and provide services during construction. The design was completed in the spring of 2015 with all approvals secured so as to tender/award the Contract for the summer 2015 construction season. The Contract was awarded at the end of June to low tenderer, Marathon Drilling Co. Ltd.

Existing Conditions

Structure

The existing culvert structure under Prince of Wales Drive that conveys Nepean Creek to the Rideau Canal, a UNESCO-designated World Heritage Site, was built in stages between the early 1940s and 1960s (see Figure 1 and Figure 2). It was a composite section consisting of a structural plate corrugated steel pipe (SPCSP) culvert and a concrete frame culvert. A large stormwater management facility (SWF) was constructed upstream of the culvert in the mid-1990s to treat urban runoff from an approximately 991 hectare drainage area. The outlet from the final treatment cell at the facility's downstream end flowed through the culvert to outlet into the Rideau Canal, some 100 m downstream.

The culvert was approximately 10 m deep and 65 m long. From the upstream end on the west side, the SPCSP section was about 34.5 m long and consisted of an elliptical shape with an approximate span and rise of 4,000 mm x 4,300 mm, respectively, with a 5 mm to 6 mm steel plate thickness. The inlet to the culvert extended beyond the embankments. Corrosion of the existing structure was concentrated at and below the water line.

The concrete culvert section was an open footing assembly with plain concrete walls and reinforced concrete beam and top slab structure. The approximate span and height of the concrete culvert section above the waterline was 5,300 mm x 3,100 mm, respectively. The overall length of this section from the end of SPSCP section to the outlet was approximately 21.0 m. The SPCSP section overlaid the top of the concrete culvert slab, but was overlapped by the concrete culvert sidewalls. Erosion and deterioration of the structure had caused collapse of the northeast wingwall and a slope failure in the east (downstream) embankment.

Utilities

Shallow buried and deeper utilities existed in the work area. Working around and near buried and/or overhead utilities is a common challenge of urban tunnelling. A 300 mm vital, extra high pressure gas transmission main was located at the bottom of the embankment, just in front of the inlet to the existing culvert. Telecommunications and fibre optic cables were present on the east side of the roadway, visibly hanging across the east embankment slope failure. Hydro poles were located along the west side of the roadway. A 400 mm diameter municipal watermain was buried approximately 2.4 m under the east side of the travelled portion of the roadway.

Figure 1. Upstream end of culvert, before construction.

Figure 2. Downstream end of culvert, before construction.

Traffic

Prince of Wales Drive is classified by the City as an urban arterial roadway. Running parallel to the Rideau Canal, it also has "Scenic Entry Route" status to the downtown core of the Nation's capital. At the location of the culvert crossing, it supports four travel lanes within a 13.5 m wide paved surface, and a 1 m wide paved shoulder adjacent to a 0.5 m granular shoulder on both the west and east sides. The posted speed limit is 60 km/hr. The existing AM and PM peak traffic volumes (from 2013 counts) were in the order of approximately 1,500 vehicles per hour.

In April 2011, the Transportation Committee of the City of Ottawa received the results of a Schedule C Class Environmental Assessment that proposed, in the longer term, a widening of Prince of Wales Drive to a four-lane urban divided arterial with cycling and pedestrian facilities. The design for replacement of the culvert, therefore, had to consider the ultimate planned roadway configuration.

Subsurface Conditions

Golder Associates Ltd. (Golder) was retained under a subconsultant agreement to carry out a subsurface investigation program including geotechnical, hydro-geological, and environmental testing of the soils and groundwater at the site.

Five boreholes were advanced along the expected tunnel alignment to assess the subsurface conditions. Information from five additional boreholes from previous subsurface investigation work carried out at the site was also used as a reference in analyzing soils/groundwater conditions and in developing recommendations for design and construction. The embankment fill consisted of silty sand with clay, silty clay with sand, and a trace of gravel and organic matter. The embankment fill is underlain by an alluvial sand deposit with high permeability that ranged in composition from sand to gravel to silty clay. The silty clay deposits underlay the sand deposits and are themselves underlain by stratified depositions of silt, silty sand, clayey silt, and glacial till. Bedrock was not encountered at any of the boreholes. Soils conditions within the tunnel horizon were found to be mixed, consisting of very loose to loose alluvial sand deposits, firm grey silty clay and loose to compact silty sand and embankment fill.

Monitoring wells were installed in four of the geotechnical boreholes to carry out in situ hydraulic response testing within the different stratigraphic units, recognizing that surface water and groundwater management would be required to maintain dry conditions in the excavations.

Two boreholes were also used for environmental soil/ groundwater testing, as a Phase 1 Environmental Site Assessment identified a number of parameters of concern in the embankment fill. Soil/ groundwater contamination can often be a problematic issue in urban tunnelling, with soils and/or groundwater impacted by urban land use having to be managed on site or hauled off site for treatment, at significant cost.

Design

Alternatives

Design options considered at preliminary design review included:

1. Open cut excavation and replacement.
2. Tunnel twin 2,400 mm culverts adjacent to existing culvert.
3. Remove the existing concrete section by open cut, and line and extend the SPSCP section.
4. Tunnel a new culvert and line the existing culvert.

Option 1 was seen as potentially the least costly solution. However, the City would only allow lane reductions during peak periods for two months in the summer. The nature of the deep excavations required to install the new culvert would have been such that a complete road closure would have been required. Maintaining flow in the existing watercourse during construction was also seen as a significant risk of this option.

Option 2 would allow for gravity flow through the existing culvert while twin tunnels were driven adjacent to it. The existing culvert would have then been abandoned in place. If the recommended horizontal separation of two tunnel diameters was respected, this option would have required property acquisition on the downstream side, which was not desirable from the City's perspective. Relatively significant changes to the upstream and downstream watercourses would also have been necessary to meet the new stream alignment that would have been required. Driving two new tunnels also represented the highest cost alternative.

Option 3 was discounted for the same reasons as Option 1.

Option 4 was the preferred design concept. It included driving a new concrete pipe tunnel, then lining the existing tunnel with a new concrete pipe. This option provided the advantages of a long expected service life, reasonable capital cost and flexibility in construction staging, such that flows in the watercourse could be conveyed through the existing culvert during tunnelling, then through the newly constructed tunnel during sliplining. The new tunnel, however, had to be driven at less than the recommended separation from the existing culvert to keep the facilities within the municipal right of way on the downstream side.

Hydraulic Analysis

The City's Sewer Design Guidelines require that a culvert under an urban arterial roadway with a span of 6 m or less must be designed not to overtop during a storm with a 1:50 year recurrence. A hydraulic analysis was required to ensure the preferred design could meet this criterion. The hydraulic analysis was also required to size the tunnel and the slipline pipe such that under the 1:100 year storm, the backwater generated at the culverts would not affect the operation of the upstream SWF. This latter criterion was, ultimately, the constraint that drove the hydraulic design and the sizing of the facilities.

HEC-RAS simulation results for the preferred design option indicated that twin 2,100 mm diameter concrete pipes had sufficient capacity to convey both the 1:50 and 1:100 year peak flows without roadway overtopping and without the backwater affecting the operation of the SWF. However, a detailed field survey of the underside of the roof beams inside the concrete box section revealed that the maximum size concrete pipe that could fit through the opening at the transition between the SPSCP section and the box culvert was 1,950 mm. Additional modelling runs were carried out, as a sensitivity analysis, to refine invert elevations and slopes to prove that the hydraulics of the smaller sliplining pipe were acceptable. The refined model predicted an increase in outlet velocities due to super-critical flow conditions within the barrels during the 1:100 year storm. As a result, a refined geomorphological design was required with new erosion control measures incorporated at the culvert inlet and outlet. Bank stability measures were also included in the final channel alignment as the angle of approach at the upstream end was increased because of the geometry required to convey the flow through two culverts instead of one. The angle was also increased because the new culverts had to be lengthened to accommodate the future widening of Prince of Wales Drive.

Traffic

CastleGlenn Consultants Inc. was retained to develop a Traffic Control Plan Strategy to address the impacts of short-term lane closures on the operating conditions of the roadway and the nearby signalized intersections. The schematic plans for managing traffic through the work zone for each anticipated construction stage were included in the tender documents to help Contractors assess the constraints under which they would be required to operate.

Approvals

Approvals were required from federal, provincial, and municipal authorities prior to undertaking the work. Specifically, the approvals issued by Parks Canada and the local Conservation Authority included the requirement for prescriptive environmental protection, and erosion/ sediment control measures to be implemented. There was also a prohibition placed on any in-water work during the fish spawning period, between March 15 and July 1. This timing restriction became a critical project constraint as construction proceeded and delays were incurred.

Selection of Tunnelling Methodology

The diameter and length of the proposed installation, as well as the soils and groundwater conditions, limited the number of tunnelling methods that would be economically viable and technically feasible. Although a number of potential methods were reviewed in this context, the choice of equipment and method of tunnelling was left to the Contractor to determine.

As noted, the geotechnical investigation concluded that soils conditions within the tunnel horizon would be mixed, and could be expected to consist of very loose to loose alluvial sand deposits, firm grey silty clay and loose to compact silty sand and embankment fill. The unknown, potentially variable nature of the embankment fill, particularly on the east side of the crossing, was a significant project risk. It was noted that cobbles, boulders, trees, stumps, and other debris were to be expected, particularly on the side slopes and at the fill/native soil interface. Groundwater was also expected within the tunnel horizon.

Based on Tunnelman's Ground Classification System, the sandy soils that predominated within the tunnel horizon would generally behave as "flowing" to "running" ground. Therefore, tunnelling methods that involved an exposed and unsupported tunnel face were not considered to be feasible, unless active groundwater lowering was carried out in advance. Based on the required inside diameter of the tunnel of 2.1 m and the expected ground conditions, the initial design review concluded that either pipe jacking or pipe ramming would be feasible trenchless installation methods for this site. Open-faced tunnel boring with a TBM, using an Earth Pressure Balance TBM and/or auger boring were dismissed because they were seen to be uneconomical for such a short tunnel drive, as the machinery required for the given diameter was not locally available. Significant and costly groundwater control would also have been required.

The option of pipe jacking recognized the constraints inherent with the required size of the casing pipe, and considered open-ended jacking of a steel casing pipe through the loose soil, without removing the soil within the casing. This suggested method would avoid the open-face condition and would limit ground loss into the casing. However, for the expected drive length of over 60 m and at a casing diameter of approximately 3 m, the risks of developing excessive friction would be high. Hand mining would be required to remove some of the soil in the casing in the event that the jacking forces increased to an unmanageable level due to friction.

The obstructions expected in the embankment fill also presented a significant risk to selecting open-ended pipe jacking as the tunnelling method. The grade of the new culvert (0.85%) was critical to providing the required hydraulic capacity. Deflections in the horizontal alignment were to be avoided in order to keep the tunnel within City-owned lands. If an obstruction was encountered during jacking, there would be considerable risk to workers hand mining at the face if the ground were to flow, as well

"It was noted that **cobbles, boulders, trees, stumps, and other debris** were to be expected, **particularly** on the side slopes and at the **fill/native soil interface.**"

Figure 3

as a high probability of not achieving the grade and/or horizontal alignment requirements.

Installation of a steel casing by pipe ramming was also seen as a potentially feasible tunnelling option. The inherent risks, however, are similar to those noted above for pipe jacking. The ability to maintain line and grade with this non-steerable method, given the potential for varying soil types and obstructions, was questionable. The removal of soil from within the casing and the risks to workers if an obstruction was encountered that required hand mining to the open face, were also seen as significant.

After award, the Contractor proposed direct installation of the concrete pipe tunnel using a Tunnel Digging Machine (TDM). This face-accessible method was well suited to the anticipated changing ground conditions. Further, it is somewhat steerable, allowing for line and grade corrections, if necessary, along the drive length. It also obviated the need to install a steel casing, as concrete jacking pipe could be installed directly behind the tunnelling machine.

Tunnelling by TDM is a process of simultaneously jacking concrete pipe directly behind a steel digger shield. The material at the face is excavated using a small excavator arm as the shield is jacked forward through the earth material. The material is transferred onto a conveyor belt system that loads a muck cart that is winched out of the tunnel to the entrance shaft to be emptied at the surface. The digger shield itself has an articulating head with four hydraulic rams for steering purposes. Line and grade are continuously monitored with a laser set up in the entrance pit and is monitored by the operator in the digger shield who can make the necessary adjustments using the hydraulic rams to keep the tunnel on line and on grade. The front end of the digger shield is equipped with steel horizontal sand shelves, to allow for enhanced face stability as the machine advances through the earth.

An intermediate jacking station (IJS) was installed to better distribute the jacking forces. To reduce external skin friction and reduce jacking pressures if necessary, bentonite slurry could be injected along each concrete pipe. As well as providing lubrication, the slurry would ensure that the modest overcut of the tunnel machine was completely filled, reducing the magnitude of surface settlement. Figure 3 shows the TDM brought to site.

Construction

Tunnelling Set-Up

The west side was well suited for the entrance shaft and for the tunnelling operation, as there was access from Prince of Wales Drive, down an existing maintenance roadway into the work area. An expansive lay down and staging area was also available on the west side, near the required tunnelling location. All Contractor equipment could be located within this available area, leaving the travel lanes in the roadway almost completely unencumbered for most of the construction period. For the most part, there was very little evidence to the driving public of the work proceeding under the roadway.

A steel sheet pile cofferdam was constructed to isolate the entrance pit from the surface water channel. Due to the restricted footprint available between the channel and the tunnel face, a localized stream diversion was required to allow for the construction of the 7 m long, 5 m wide pit. This was accomplished using sections of 3 m diameter steel pipes, through which the channel flowed around the excavation and, ultimately, through the existing culvert that was still in operation. This gravity by-pass was left in place for the entire duration of the tunnelling operation. It was an important component of the overall approach to construction staging that was envisaged during the design period and one that contributed to the selection of the overall approach to renewing the structure: a new culvert by tunnelling, and a rehabilitated culvert by sliplining. Figure 4 shows the entrance pit and re-aligned channel on the west (upstream) side.

The backstop design consisted of steel plates supported by four vertical piles (acting in tension) and eight diagonal piles (acting in compression), driven through the earth and socketed a minimum of 4 m into the bedrock, for a factored jacking force of 600 tonnes. The jacking station was welded to steel rails set in a concrete mud slab, with a granular pad underneath. The working slab was attached to the backstop with steel pipes and beams, welded to the vertical and diagonal piles, to counter the horizontal jacking forces. Prior to tunnelling, a short section of 3 m diameter steel pipe was installed by open cut into the embankment face to act as a tunnel portal. Figure 5 shows the TDM and the first pipe section being jacked into place, with the existing culvert and stream diversion in the background.

Tunnelling Pipe

The pipe selected for the tunnelling was precast concrete, Class 140-D jacking pipe, supplied by Hansen Precast (now Forterra Pipe & Precast). The pipes were 2.4 m in length. Twenty-five pipe sections were required for the length of the tunnel specified.

Figure 4

Figure 5

Plywood was fastened around the spigot end of each pipe in the field to limit the potential for damage to the pipe from the hydraulic rams during the jacking operation.

Tunnelling

After TDM procurement delays, the 24-hour/day tunnelling operation began on October 13, 2015. Initially, production averaged about two pipes per 12-hour shift. The soils conditions initially were mostly sand and gravel, with grey clay seams in the lower part of the tunnel face. Initial jacking pressures were in the 1,000–1,500 psi range.

After six pipe sections were successfully installed, the jacking pressures required to advance the tunnel were observed to increase to approximately 3,000 psi. The soils conditions were sandy gravel with cobbles, with re-occurring grey clay seams. Some seepage of ground-water through the face was observed, but generally groundwater management was not a significant concern during tunnelling. During jacking of the seventh pipe section, at 3,000 psi, the backstop was observed to have rotated and moved, with the top and bottom flanges of the main support girder having been bent around the web. The welds connecting the main jacking base to the section holder extension fractured.

The backstop failure occurred at a jacking pressure of about 3,200 psi, or 415 tonnes – well below the factored jacking resistance. Ultimately, it was the friction between the piles and the bedrock that had failed. In reviewing the possible causes of failure, the following was noted:

- It was suspected that the main contributing factor that led to the failure was that the piles were not grouted for the full length of the rock socket (4,000 mm), as they were designed to be. This factor alone would have been enough to cause failure.
- A factored rock bond of 1.0 MPa was used in the design of the backstop, which may not have been sufficiently conservative and may not have been achieved due to grout inconsistency and/or water infiltration.
- If pile embedment was less than the design value of 4,000 mm, there would have been insufficient bond length.
- The horizontal bedding planes in the bedrock could have led to failure along a bedding plane, instead of a horizontal failure as is typically assumed.

The backstop failure occurred during the night shift. During the following day, the Contractor began remedial measures to correct the failure so that tunnelling could resume. Their solution was to install cables through the existing vertical piles to act as tie-downs. The cables were to be installed about 3,500 mm deeper than the original rock sockets. As the cables were being drilled through the existing casings, the observation was made that the piles were not grouted for the full length of the rock socket, confirming the suspected reason for the failure.

After each of the four vertical holes were deepened through the bedrock, eight 16-gauge steel cables were placed in each casing and fully grouted in place. Once the grout had set, the cables were tensioned to 300,000 pounds, the base slab was re-poured, the jacking station was re-set and the backstop was repaired. In total, the backstop failure and the remedial measures that were required to be put in place resulted in a delay of five days to the critical path schedule.

Very soon after tunnelling resumed, during installation of the eighth pipe section, difficult ground conditions and debris began to appear at the face. Roots, trees stumps, logs, and boulders had to be removed by hand or by chain saw at the face. An intermediate jacking station was installed between the seventh and eighth pipe sections and bentonite slurry was used consistently to reduce the external skin friction, to aid in reducing the jacking pressures. Due to the obstructions at the face, the production rate was halved, with pipe sections 8, 9, and 10 taking a full 12-hour shift each to install. Jacking pressures reached 4,000 psi during this period. At maximum jacking pressures, the braced connections at the jacking station were observed to be distressed; welds were tearing and bolts were breaking. The backstop was also observed to flex and rebound with increasing/decreasing pressures.

While the ninth pipe section was being jacked, a failure at the face was observed, with sandy material sliding into the tunnel from above the casing. Immediately the digger shield was advanced farther into the ground to stabilize the sloughing material. While remedial action such as filling the void with grout was not undertaken, the location of the loss of ground was marked on the surface and carefully monitored for settlement as tunnelling continued. Ultimately, the loss of ground manifested itself in a 125 mm settlement in the asphalt surface directly over the tunnel. This settlement, however, was distributed over a sufficient distance along the roadway that traffic was not materially impacted.

The obstructions present at the face during jacking of pipe sections 8, 9, and 10 were not encountered as pipe sections 11 through 14 were jacked into place. Production returned to two pipes per 12-hour shift. Soils removed from the face were mixed, consisting mostly of wet clay underlying sandy material. Jacking pressures were maintained at about 4,000 psi during this period.

During jacking of pipe section 15, pressures were reaching 5,500 psi. The IJS was mobilized in an attempt to reduce the jacking pressures and bentonite slurry was being pumped continuously. The face consisted mostly of clay and sandy till, with a significant number of boulders that had to be removed from the face. With the mixed ground conditions and extensive boulders and woody debris at the face, the Contractor's decision to advance the tunnel with a face accessible TDM was more than vindicated.

Pipes 15, 16, 17, and 18 were jacked through very difficult soils conditions, with hand mining often being required to remove boulders and logs present at the face. The larger logs had to be cut with a chain saw at the face in order to remove them.

It took four 24-hour shifts to push pipe 17 into place. During this time, jacking pressures exceeded 7.000 psi, with the measurement of pipe advancement being done in inches. Conditions worsened during jacking of pipe 18, when old formwork was observed at the face. Although the TDM was steered slightly in an attempt to avoid this new obstruction, the quantity of stumps and logs prevented any measurable deflections in the tunnel alignment. After it took three shifts to push pipe 18 into place, the Contractor moved forward with excavating the slope on the downstream side in an attempt to expose the front of the TDM and to remove the obstructions; however, the tunnel machine had not advanced far enough underneath the roadway to allow for a safe and stable excavation that would not have compromised the road. Pipe 19 was jacked through boulders, stumps, logs and was scraping against the formwork and, ultimately, a concrete wall running close to parallel to the tunnel alignment. During the fourth shift pushing pipe 19 into place, with jacking pressures over 7,000 psi, advancing inches at a time, the backstop failed catastrophically and the tunnelling had to be halted.

The buried concrete abutment that ultimately led to the abandonment of the tunnelling was not noted on any reference drawings, nor was it discovered during any of the subsurface investigation programs. Tunnelling halted approximately four pipes (approximately 10 m) short of the sheet piled exit pit on the downstream side. The combination of significant obstructions and the resultant slow-downs in production, together with the need to maintain pressure on the soil shelves at the face of the TDM led to pressure build-up on the backstop beyond its capacity. It was inferred that the machine had seized in place in the tunnel. A new approach to completing the pipe installation was required.

An excavation to expose the front of the TDM, remove it and continue with open cut installation of the remaining pipe sections would have extended into the roadway. This option, although considered, was not preferred due to the significant impact on commuter traffic. Unanticipated construction-related inconveniences are a particularly sensitive issue in the City of Ottawa. A less intrusive solution had to be found.

After a thorough review, it was determined that the front face of the TDM could be accessed by open cut excavation from the downstream (east) side and shored such that the excavation would not affect the roadway. The Contractor suggested that the entire inner workings of the TDM could be stripped out of the protective housing and a concrete pipe of the required diameter could be inserted inside the "can." The remaining pipe sections could then be installed by open cut or, if necessary, jacked into place from the downstream side.

Within two days of the second backstop failure and halting of tunnel advancement, the Contractor began the work of stripping all of the internal workings of the TDM from the protective housing. Precise measurements of the internal diameter of the "can" were taken so that custom pipe sections could be manufactured to fit inside it. The external diameter of a standard 2,100 mm, 140-D jacking pipe would not fit. Two pipe sections with thinner walls, resulting in less cover over the reinforcing steel, were manufactured by Forterra Pipe and Precast and shipped to the job site while the work of excavating and shoring the east side, to allow access to the head of the TDM, was taking place. At the same time, the work of stripping the "can" and preparing it for sliplining was happening inside the tunnel.

The open cut excavation on the east side was successful in exposing the front face of the TDM. During the course of this excavation, large pieces of the concrete abutment, that had ultimately stopped the tunnelling operation, were also removed. Considerable difficulty was experienced pushing the custom pipe sections into the "can," as the steel housing had "squeezed" such that the casing was no longer perfectly round. Ultimately, the pipes had to be into place from the shored excavation on the east side. Once the "can" was lined, the remaining sections of concrete culvert pipe were placed in open cut without incident.

This innovative solution to what could have been a very disruptive and costly problem was developed and implemented by the Contractor in a matter of days, thereby significantly reducing the impact to the overall construction schedule. The pipe supplier, Contractor and Contract Administration team implemented this solution by working together to keep the

Figure 6

Figure 7. Upstream end of culvert, after construction.

Figure 8. Downstream end of culvert, after construction.

construction moving, with almost no down time or additional costs to the Contract, in the face of what could have been significant delays.

Sliplining

With the tunnel pipe in place, the Contractor, was able to divert the surface water channel through the new pipe so that sliplining of the existing culvert could be carried out. The specifications envisaged a standard sliplining operation, with precast concrete culvert sections jacked into place from a shored pit on the upstream (west) side.

Rather than advancing sheet piling, excavating, constructing a backstop with battered piles and a jacking pad with rails, the Contractor developed an innovative approach to inserting the pipes into the existing culvert. A scoop tram, normally used in underground mining, was modified for handling and placement of the 7.2 tonne pipe sections. The modified scoop tram (see Figure 6) was able to access the existing culvert from the upstream side, where the 4,000 mm CSP opening provided sufficient clearance for the equipment.

The existing pipe was prepared for sliplining by cleaning the debris and flushing the sediment. In the downstream concrete box section of the composite existing culvert, concrete was poured to line and grade and steel rails were set in the concrete so that the new culvert pipe could slide along the rails, being pushed from the upstream side, as the scoop tram was too big to drive through the box culvert. The entire length of the existing culvert was lined with new 1,950 mm precast concrete pipe by this innovative method in less than two days. Figure 7 and Figure 8 show the finished work.

Lessons Learned and Recommendations

This project is presented as a case study of the inherent difficulties of tunnelling in an urban environment. Challenges, related specifically to urban tunnelling, were identified and addressed through the design, approvals, permitting, and construction phases of the work.

Buried utilities are common in urban environments and adequate measures to properly locate them, as part of the pre-design investigations, are critically important. A high-pressure vital gas main was discovered well off the roadway, just in front of the inlet of the existing culvert, during site visits and through the locate process required for the borehole drilling. This unexpected utility was in direct conflict with the required location of the entrance pit and, ultimately, the footings location for the headwall. Relocation prior to construction, at significant unanticipated cost, was the only option. This delayed the tendering of the new culverts by one full year, as the planning, design, and construction associated with relocating this vital piece of natural gas infrastructure took approximately eight months. Telecommunications cables on the east side also had to be relocated, as they were, before construction, hanging unprotected across the area of slope failure. Tunnelling also had to advance under a live 400 mm diameter municipal watermain.

Due to the footprint required for not only the tunnelling equipment, but for the supporting equipment as well, property issues can often be challenging when tunnelling in an urban environment. Acquiring temporary construction easements from private property owners can be time consuming and expensive. For this project, adequate municipally-owned property was available for the set-up and staging areas; however, the final location of the new tunnelled pipe was determined by the limit of the municipal property on the downstream side. This ultimately became a significant project risk, as the new tunnel had to be driven without the recommended horizontal separation from the existing culvert in order to keep the final alignment within municipally-owned lands. There were significant concerns about the poor condition of the existing culvert (both the CSP and the concrete sections) and its ability to withstand any additional stresses induced by the adjacent tunnelling operation. Collapse of the existing culvert would have been catastrophic, as it would have blocked the flows in the watercourse and would have triggered an open cut excavation and a closure of the roadway. The magnitude of the stress increase in the surrounding soil

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and the resulting displacement were very difficult to estimate theoretically, given that the tunnelling methodology was not prescriptively identified in the Contract. Therefore, Contract language was developed to require that the Contractor monitor any lateral displacement of the existing culvert to ensure that it was not being subject to excessive or permanent deformations during tunnelling. A contingency plan to shore the tunnel in the event of unacceptable deformations also had to be developed by the Contractor. Measurement and reporting of the lateral movement of the existing culvert was required daily.

Traffic management is a significant concern with any municipal infrastructure renewal work in an urban environment. Prince of Wales Drive is a heavily-travelled urban arterial, and an important north-south commuter route. A detailed Traffic Control Plan Strategy was developed during the design to address the impacts on queue lengths and signal operation during short-term lane closures or restrictions required by the Contractor's operations, so as to minimize the impacts to the users of the corridor and surrounding area. Cycling movements through the construction zone were also considered in the Plan. By selecting tunnelling and trenchless renewal as the design approach, traffic impacts were minimized; even so, the Plan, as developed, was implemented in the field and was successful in limiting impacts to the travelling public over the duration of the construction period.

Tunnelling is typically a 24-hour operation so as to keep the forward momentum of the tunnel moving to avoid increases in external friction and the resulting possibility of the tunnel seizing in place, and to minimize face instability. In an urban environment, with residential houses close by, 24-hour work for an extended period can be very disruptive. Special approval from elected officials is required. With the delays resulting from slow advancement due to obstructions and failures of the backstop, the period in which 24-hour work was required was much longer than originally communicated to the local Councillor and the residents. The City managed this potentially delicate issue by proactive communication of technical challenges being experienced. The Contractor also erected noise shields around compressors and other stationary equipment and eliminated muck hauling from the overnight shifts to minimize noise generation.

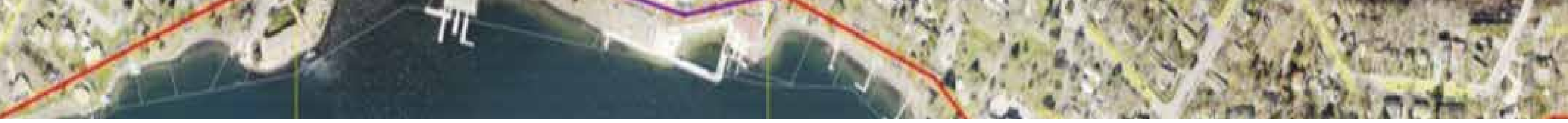
The watercourse being conveyed by the culvert is immediately downstream, and provides the outlet for, an engineered SWF. The sizing of the replacement culvert was driven, for the most part, by the requirement to not affect the operation of this facility under the design storm. Given that the culvert is located well beneath the roadway, the sizing of the new structures could potentially have been reduced if only overtopping was a consideration. The hydraulic analysis to size the new culvert was complicated by having to consider the effects of the backwater on the operation of the SWF. However, during construction, manipulation of the outlet weirs allowed for some retention and storage of flow within the SWF and allowed for a more predictable outlet rate through the construction zone. This was helpful in managing flows through the work area, particularly during more significant storm events. The flow retention also provided some lead time for the Contractor to better secure the site in advance of higher flows in the watercourse due to rain or snowmelt events.

Conclusion

This project presented many of the challenges particular to urban tunnelling. The most significant was the varying nature of embankment fill and obstructions encountered within the tunnel horizon. Although a comprehensive subsurface investigation program was undertaken, the fill placed as part of the urbanization of the area contained non-homogeneous materials that, ultimately, led to failure of tunnel advancement and a requirement to abandon the TDM in place. In hindsight, ground conditions would have dictated that a standard TBM be chosen rather than a TDM; however, given the short drive length, selection of this technology may have been cost prohibitive. Balancing these risks and costs over larger diameter, short drives can often be an inherent risk of urban tunnelling.

The pragmatic solutions developed to overcome the challenges experienced during construction, thereby limiting the impacts of the failure to complete the tunnel on the public, and on the overall project cost and schedule, were only possible through a collaborative approach to construction management. The Contractor, Owner, and Contract Administration team worked together to develop innovative design and engineering solutions that controlled construction risks. Ultimately, a high-quality end product that met all the original project objectives was delivered under budget.

The project was awarded the City of Ottawa's Environmental Excellence Award for 2016.



Northwest Arm Trunk Sewer Rehabilitation – TT Project of the Year Runner Up

Halifax Water required the renewal of an inaccessible 100-year-old, large diameter, 4,000 m long trunk sewer that was exfiltrating into the Northwest Arm inlet, a major recreational and natural environment asset in Halifax, Nova Scotia serving a population of over 360,000. Halifax Water's primary goals for this project was to remove debris, restore the structural integrity, eliminate exfiltration, establish a corrosion barrier, and extend the life of the sewer up to 75 years, all while minimizing the social, environmental, and cost implications associated with construction.

CIPP rehabilitation of the Northwest Arm Trunk Sewer (NATS) offered Halifax Water a solution that addressed all the primary goals of the project and also necessitated the removal of debris from the sewer, gaining back its original intended flow capacity.

The Northwest Arm Trunk Sewer (NATS) rehabilitation required the planning and engineering for an innovative and record-breaking solution extending the service life and eliminating contamination of the coastline. The project was executed in a cost-effective manner while significantly reducing social and environmental impacts.

The ambitious goals of this project presented several significant challenges including extremely limited access, accelerated completion schedule and complex engineering design of a CIPP in an arch-shaped pipe.

The Northwest Arm Trunk Sewer was one of the most challenging Cured-In-Place-Pipe (CIPP) rehabilitation projects ever completed in North America. Several Canadian CIPP installation records were broken in the completion of this project (including longest single continuous installation length at 682 m). The engineering for this project included CCTV inspection, condition assessment, feasibility study, constructability, detailed design, tendering, contract administration, and site inspection for the rehabilitation of more than 4,000 m of a combined trunk sewer ranging from 1,200 mm diameter round pipe to 1,200 mm x 1,500 mm arch pipe, located

in some of the most difficult to access residential terrain in Halifax.

Located on the coast of the Northwest Arm inlet, the NATS alignment meanders along the shoreline anywhere from 0–10 meters from the water's edge and is land locked by a CN rail track with bridge access only. The NATS presented numerous accessibility challenges including being located mainly on built up multimillion dollar historic residential water front properties, steep shoreline slopes, 100-year-old load restricted CN bridges and a hydro corridor.

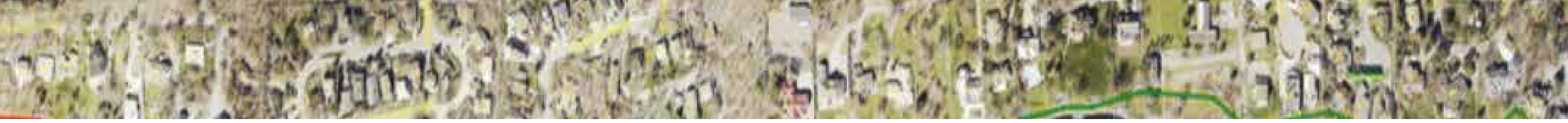
This project was Canadian Water Wastewater Fund (CWWF) financed with an aggressive schedule that required this project to be completed by March 31, 2018. Typically, a project of this magnitude and complexity would be planned and constructed over at least 24 months; however, the project was successfully finished from planning to completion of construction in just 16 months to meet the project schedule.

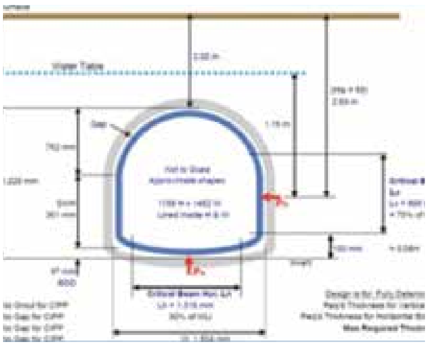
Engagement with key stakeholders was a vital component of the success of this project. Due to the location of the sewer crossing multi-million dollar historic ocean front residences, it was critical that property owners were engaged throughout the project. Public consultation began in the planning stage, providing the residents with a clear understanding of the issues and concerns with the NATS condition and the benefits to the community that would be achieved through rehabilitation of the sewer.

The off-street location within the ocean view backyards of multi-million dollar homes and the steep terrain surrounding the sewer presented significant accessibility challenges which resulted in approximately 3,000 m of the total 4,000 m being installed from just four access points. This required numerous CIPP installation lengths being completed in excess of 400 m versus the typical installation, which range from 100 m – 150 m in length. Furthermore, the limited access required an innovative on-site fabrication approach to reduce the weight of material trucks required to enter the site over the load restricted bridges.

The existing condition also required heavy debris removal of over 750 m^3 from just five access locations, pulling debris over lengths in excess of 500 m in some cases.

While CIPP was a constructible solution to address access and schedule challenges associated with the project, the design of the CIPP liner required a unique approach. CIPP design standards (ASTM F1216) are founded on the basis of a circular sewer and are not applicable for non-circular sewers. The use of CIPP on the non-circular portions of the NATS





totaled approximately 2,000 m, requiring a design method to be developed. As a result, a highly technical and a unique design approach utilizing a first principles methodology to develop a specialized non-circular CIPP design calculation for the arch-shaped portions of the sewer was established. The design approach assessed the pipe cross-section in three distinct components: the arch top, the vertical sides, and the dished bottom.

The design parameters for each of these individual components were established, along with design equations to identify the CIPP thickness required to meet the expected loads. The design methodology expanded the limitations of the CIPP technology.

The typical alternate construction methodology of open cut pipe replacement was also discussed in detail with the public. Given the alternative of replacing this sewer through a naturally beautiful shoreline, the CIPP allowed a considerably smaller construction footprint, providing significant reductions in social, environmental, and economic impacts.

While the replacement of the NATS was socially unimaginable, it is estimated that overall cost savings through the use of CIPP was between 50% and 60% versus replacement. It was further estimated the total construction period was reduced by as much as six to eight months.

CIPP is a structurally sound pipe within the existing pipe, providing considerable economic and socioeconomic benefits eliminating the need for significant excavation. In the case of the NATS, while some minor excavation of existing MHs was required, no linear length of sewer pipe required excavation. This significantly reduced the cost and social disruption associated with excavating through the yards of the homes along the Northwest Arm shoreline, allowing residents and the public to continue to use the recreational shoreline during construction. To further ensure the successful completion of the project, a risk workshop was undertaken at the inception of the project. As a result, rehabilitation technologies were reviewed to identify all risks associated with the NATS rehabilitation using CIPP and slip lining.

The top risk identified was the impact of major rain events which could exceed the capacity of the by-pass system established to complete the work. This risk was substantially mitigated through the retrofitting and upgrading of the primary sewerage pump station feeding the NATS, allowing the station to divert flow to another trunk sewer system and treatment facility. The design, tendering and contract administration was completed prior to the sewer rehabilitation work and within the overall project schedule. This not only provided significant benefits to the rehabilitation project but also reduced the CSO frequency due to rain events as this diversion was made to be a permanent alteration to the sewer collection system.

The original construction of the NATS involved a combination of trenching and hand tunnelling using poured concrete pipe or clay tile block. The sections of the sewer that were constructed using the clay tile block had significant gaps between the blocks that allowed the exfiltration of sewage into the Northwest Arm inlet when the combined sewer surcharged during rain events. This resulted in contamination of the water and an unpleasant sewage smell along the coast of the Arm that was noticeable to the local residents. The installation of the CIPP provided a pipe within the sewer creating a sustainable long-term structural solution eliminating exfiltration of sewage into the ocean. The design of the liner also considered the effect of global warming and the resulting rise in ocean levels to ensure a long service life.

Project Owner: Halifax Water

Engineer: Robinson Consultants / CBCL Limited

Contractor: Liquiforce Services, Insituform, Unijet, Empipe, AtlasDewatering

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